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Calculation of Resonant Values of Electromagnetic Energy Incident Upon Dielectric Spheres

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Final Report

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Propulsion Directorate
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EDWARDS AIR FORCE BASE CA 93524–7048

NOTICE

FOREWORD

The work reported in this final report was performed under JON: 305800E2 with the OLAC PL/RKFE Branch at the Phillips Laboratory, Edwards AFB CA 93524–7680. OLAC PL Project Manager was Dr Frank Mead.

This report has been reviewed and is approved for release and distribution in accordance with the distribution statement on the cover and on the SF Form 298.

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14. ABSTRACT
Research and development regarding the zero-point energy of the vacuum is in its infancy, with only a handful of researchers having done serious work in the field. In this report, a theory developed by Dr. Jack Nachamkin is investigated. His theory involves the incidence of electromagnetic radiation upon a dielectric sphere and the associated resonances. If two spheres would be placed within close proximity of one another and exposed to bombarding electromagnetic radiation having a range of frequencies broad enough to cover the difference in resonant waves established would work in conjunction to create a beat frequency between the two waves which could be rectified and thus provide a source of electrical energy and a trap for zero-point energy. This work centered upon the search for at least one identifiable resonant combination of sphere radius and wave frequency.

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INTRODUCTION AND BACKGROUND

As the Air Force strives to maintain its excellence in science and technology, care must be taken to investigate unconventional areas in the hopes of creating a scientific breakthrough. Such developments keep the Air Force at the forefront of the scientific community. One such topic is the zero-point energy (ZPE) of space. Theories have been developed regarding how to tap this essentially infinite supply of energy. The tapping of such energy could have many areas of application, two of which are as an alternative energy source [Refs. 1,2] and as a field generator [Ref. 3]. The implication of nearly limitless energy regardless of location in space points to an obvious utilization of the ZPE as an enabling means of previously unrealized types of propulsion.

However, research and development regarding the ZPE is in its infancy, with only a handful of researchers having done serious work in the field [Ref. 3]. In this paper, a theory developed by Nachamkin will be investigated [Ref. 4]. His theory involves the incidence of electromagnetic (EM) radiation upon a dielectric sphere. The key characteristics of this phenomenon are a sphere of radius a and propagation constant k_1 imbedded in an infinite homogeneous medium of constant k_2, and the EM wave angular frequency, ω. The product of k_2 and a form ρ, the parameter of interest for this type of interaction. If a resonant value of ρ can be identified, then it would be desired to manufacture two spheres of slightly dissimilar size, but with each able to attain the same value of ρ, given the required EM radiation angular frequency. The two spheres would be placed within close proximity of one another and exposed to bombarding EM radiation having a range of frequencies broad enough to cover the difference in resonant ω values of the two spheres. In turn, the resonant waves established would work in conjunction to create a beat frequency between the two waves. This beat frequency could be rectified, thus providing a source of electrical energy and a tap of the ZPE.

This work centered upon the search for at least one identifiable resonant combination of sphere radius and wave frequency, as mentioned above. Work was performed at the Air Force's Phillips Laboratory (PL) at Edwards Air Force Base. Use was made of the PL's VAXCluster for computational work.

THE MIE SCATTERING AND ITS ASSUMPTIONS

The main area of concern addressed in this report is the interaction of electromagnetic radiation with a dielectric sphere; i. e., the diffraction of a plane wave by a sphere, more commonly known as Mie scattering [Ref. 5]. It is assumed that the sphere is made of a homogeneous material and that the medium surrounding the sphere is a vacuum. The incident radiation is assumed to be a plane wave propagating in the $\boldsymbol{z}$-direction. Electrical vibrations of the incident wave are assumed to occur in the $\boldsymbol{x}$-direction, with magnetic vibrations in the $\boldsymbol{y}$-direction, as illustrated in Figure 1.

As explained in Stratton [Ref. 6], a forced oscillation of free and bound charges, synchronous with the applied field, arises when a periodic wave falls incident upon a body, regardless of the sphere's material. This creates a secondary field in and around the body. The vector sum of these primary and secondary fields gives the value of the overall field. In theory, a transient term must be added to account for the failure of the boundary conditions to hold during the onset of the forced oscillations. However, in practice it is acceptable to consider only the steady-state, synchronous term because the transient oscillations are quickly damped by absorption and radiation losses.

A plane wave falling upon a sphere is the simplest of such instances, but it is the central focus of this study. In Stratton's notation, the sphere has a radius a and a propagation constant k_1. It is located within an infinite, homogeneous medium with propagation constant k_2. Region 1 and region 2 have permittivities ε_1 and ε_2, respectively, and permeabilities μ_1 and μ_2, respectively. Expanding the incident field in vector spherical wave functions, with E_0 being the amplitude of the time harmonic electric field, yields [Ref. 6]:

$$\boldsymbol{E}_i = E_0 e^{-i\omega t} \sum_{n=1}^{\infty} i^n \frac{2n+1}{n(n+1)} (\boldsymbol{m}_{o1n}^{(1)} - i\boldsymbol{n}_{e1n}^{(1)}) \quad (1)$$

and, for the magnetic field:

$$\boldsymbol{H}_i = -\frac{k_2}{\omega \mu_2} E_0 e^{-i\omega t} \sum_{n=1}^{\infty} i^n \frac{2n+1}{n(n+1)} (\boldsymbol{m}_{e1n}^{(1)} + i\boldsymbol{n}_{o1n}^{(1)}) \ , \quad (2)$$

where

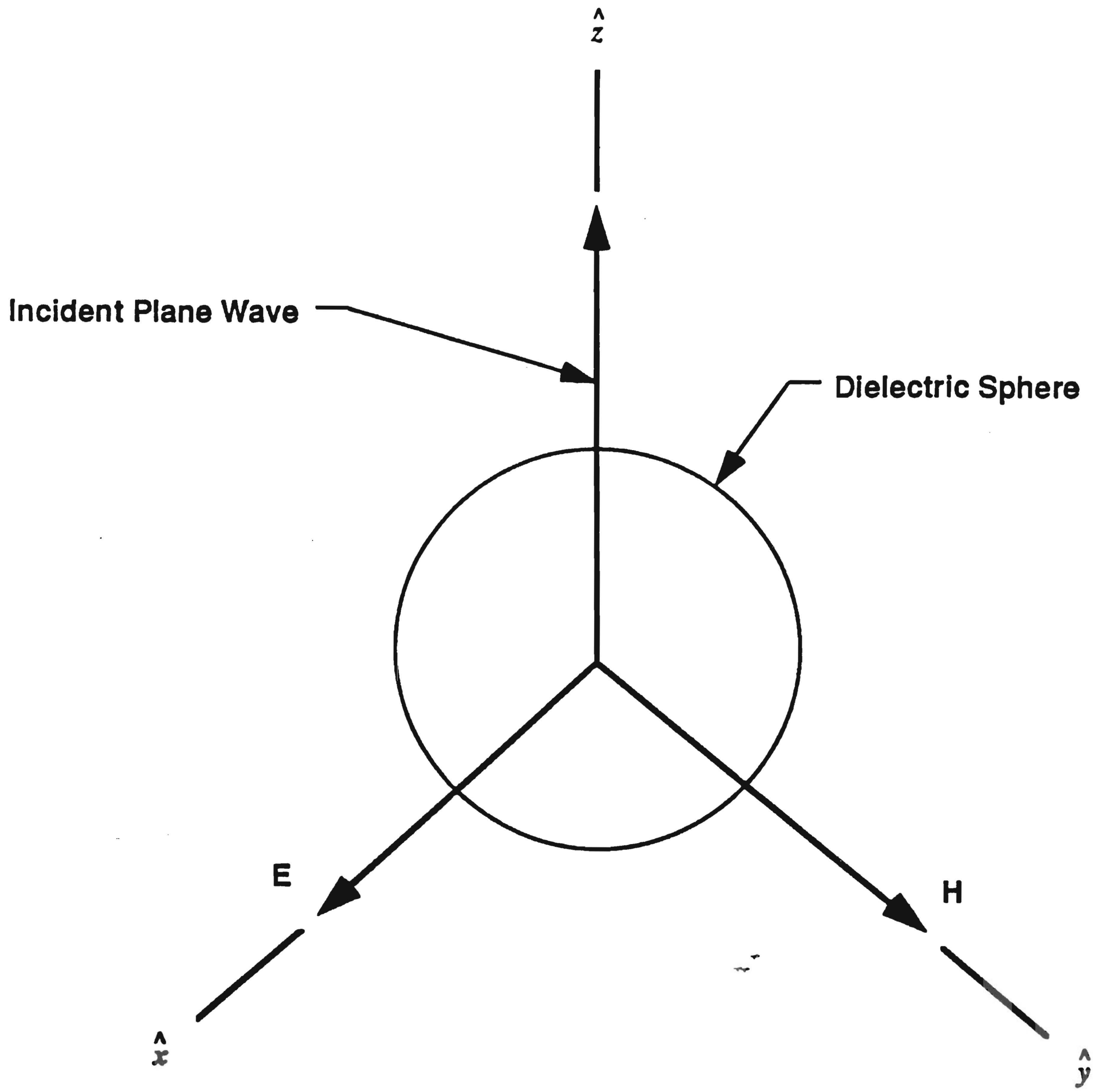

Figure 1
Incident Wave and Sphere

$$\mathbf{m}^{(1)}_{\substack{o1n\\e1n}} = \pm \frac{1}{\sin\theta} j_n(k_2R)\, P_n^1(\cos\theta) \begin{matrix}\cos\\ \sin\end{matrix}\phi\, \mathbf{i}_2 - j_n(k_2R)\, \frac{\partial P_n^1}{\partial\theta} \begin{matrix}\sin\\ \cos\end{matrix}\phi\, \mathbf{i}_3 \tag{3}$$

and

$$\mathbf{n}^{(1)}_{\substack{o1n\\e1n}} = \frac{n(n+1)}{k_2R} j_n(k_2R)\, P_n^1(\cos\theta) \begin{matrix}\sin\\ \cos\end{matrix}\phi\, \mathbf{i}_1 + \frac{1}{k_2R} [k_2R j_n(k_2R)]' \times$$

$$\frac{\partial P_n^1}{\partial\theta} \begin{matrix}\sin\\ \cos\end{matrix}\phi\, \mathbf{i}_2 \pm \frac{1}{k_2R\sin\theta} [k_2R j_n(k_2R)]' P_n^1(\cos\theta) \begin{matrix}\cos\\ \sin\end{matrix}\phi\, \mathbf{i}_3 \,. \tag{4}$$

A prime represents differentiation with respect to the argument k_2R. The unit vectors $\mathbf{i}_1$, $\mathbf{i}_2$, and $\mathbf{i}_3$ represent the directions of increasing r, θ, and ϕ, respectively, in spherical coordinates. They are presented in Figure 2.

The electric and magnetic fields of the wave transmitted into the sphere (region 1), i. e., $R < a$, can be expanded using the same functions [Ref. 6]:

$$\mathbf{E}_t = E_o e^{-i\omega t} \sum_{n=1}^{\infty} i^n \frac{2n+1}{n(n+1)} (a_n^t \mathbf{m}^{(1)}_{o1n} - i b_n^t \mathbf{n}^{(1)}_{e1n}) \tag{5}$$

and

$$\mathbf{H}_t = -\frac{k_1}{\omega\mu_1} E_o e^{-i\omega t} \sum_{n=1}^{\infty} i^n \frac{2n+1}{n(n+1)} (b_n^t \mathbf{m}^{(1)}_{e1n} + i a_n^t \mathbf{n}^{(1)}_{o1n}) \,. \tag{6}$$

If $j_n(k_2R)$ is replaced by $h_n^{(1)}(k_2R)$ in Eqs. (3) and (4), the functions $\mathbf{m}^{(1)}$ and $\mathbf{n}^{(1)}$ in Eqs. (5) and (6) become $\mathbf{m}^{(3)}$ and $\mathbf{n}^{(3)}$. The outgoing fields ($R > a$) are then represented by:

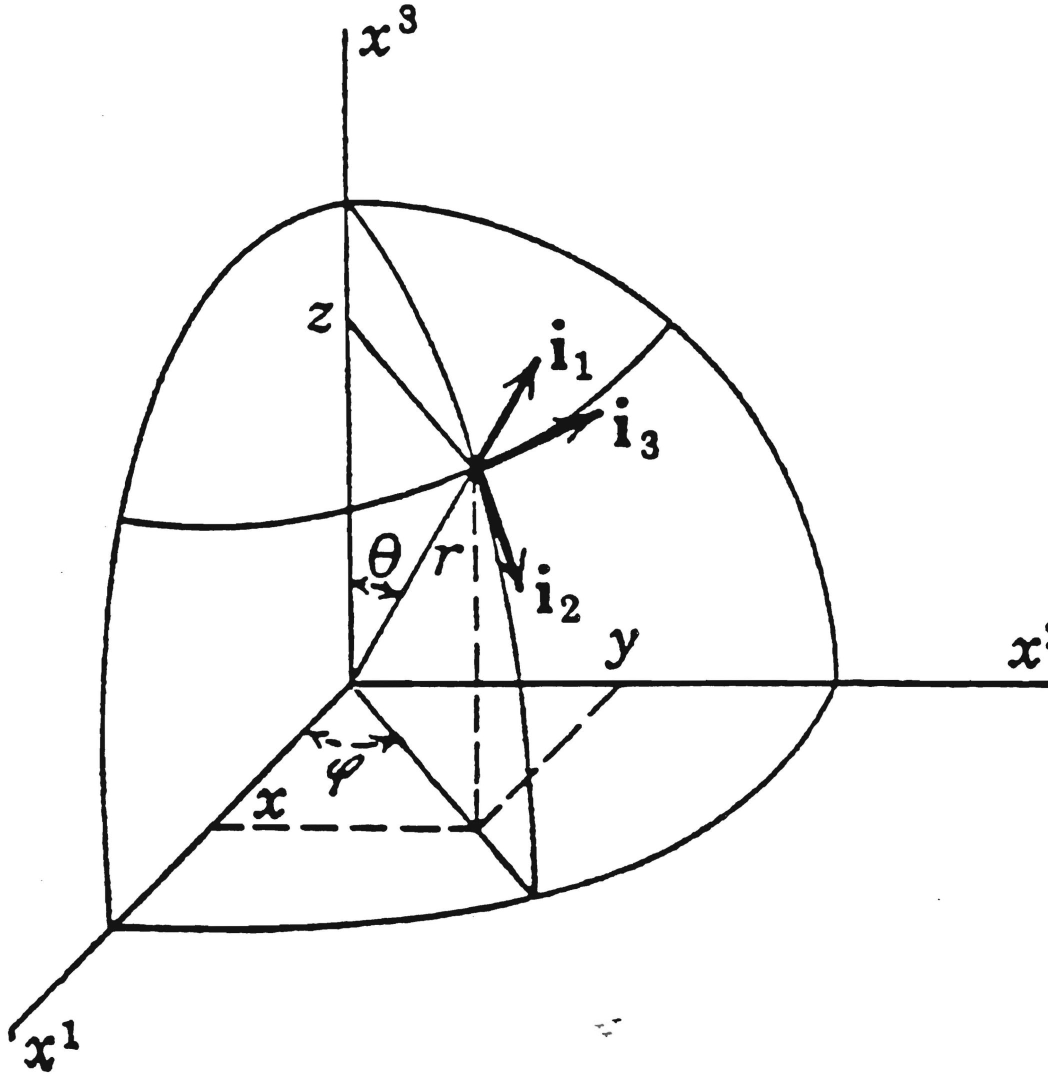

Figure 2
Spherical Coordinate System with *i* Unit Vectors

$$\boldsymbol{E}_r = E_o e^{-i\omega t} \sum_{n=1}^{\infty} i^n \frac{2n+1}{n(n+1)} (a_n^r \boldsymbol{m}_{o1n}^{(3)} - i b_n^r \boldsymbol{n}_{e1n}^{(3)}) \tag{7}$$

and

$$\boldsymbol{H}_r = -\frac{k_2}{\omega \mu_2} E_o e^{-i\omega t} \sum_{n=1}^{\infty} i^n \frac{2n+1}{n(n+1)} (b_n^r \boldsymbol{m}_{e1n}^{(3)} + i a_n^r \boldsymbol{n}_{o1n}^{(3)}) \quad . \tag{8}$$

It should be noted that k_1 in Eq. (6) is replaced with k_2 in Eq. (8), as Eq. (8) represents the resultant wave in the medium surrounding the sphere (region 2).

Being sought are the resonant ρ values for which the a_n^t and b_n^t coefficients are infinite. To find a_n^t and b_n^t, the boundary conditions at the sphere radius (radius $R = a$) are needed, i. e., continuity of the **E** and **H** values at the surface. Thus,

$$\boldsymbol{i}_1 \times (\boldsymbol{E}_i + \boldsymbol{E}_r) = \boldsymbol{i}_1 \times \boldsymbol{E}_t \tag{9}$$

and

$$\boldsymbol{i}_1 \times (\boldsymbol{H}_i + \boldsymbol{H}_r) = \boldsymbol{i}_1 \times \boldsymbol{H}_t \ , \tag{10}$$

which lead to two pairs of inhomogeneous equations:

$$a_n^t j_n(N\rho) - a_n^r h_n^{(1)}(\rho) = j_n(\rho) \tag{11a}$$

$$\mu_2 a_n^t [N\rho j_n(N\rho)]' - \mu_1 a_n^r [\rho h_n^{(1)}(\rho)]' = \mu_1 [\rho j_n(\rho)]' \tag{11b}$$

$$\mu_2 N b_n^t j_n(N\rho) - \mu_1 b_n^r h_n^{(1)}(\rho) = \mu_1 j_n(\rho) \tag{12a}$$

$$b_n^t [N\rho\, j_n(N\rho)]' - N b_n^r [\rho\, h_n^{(1)}(\rho)]' = N[\rho\, j_n(\rho)]' . \tag{12b}$$

Continuing with Stratton's notation [Ref. 6], the key relations are:

$$k_1 = Nk_2, \quad \rho = k_2 a, \quad k_1 a = N\rho . \tag{13}$$

Spherical Bessel functions of the first kind are denoted by j_n, while those of the third kind are denoted by $h_n^{(1)}$.

Manipulation of Eqs. (12) and (13) gives the values of a_n^t and b_n^t to be:

$$a_n^t = \frac{\mu_1 j_n(\rho)[\rho h_n^{(1)}(\rho)]' - \mu_1 h_n^{(1)}(\rho)[\rho j_n(\rho)]'}{\mu_1 j_n(N\rho)[\rho h_n^{(1)}(\rho)]' - \mu_2 h_n^{(1)}(\rho)[N\rho j_n(N\rho)]'} \tag{14}$$

and

$$b_n^t = \frac{\mu_1 N j_n(\rho)[\rho h_n^{(1)}(\rho)]' - \mu_1 N h_n^{(1)}(\rho)[\rho j_n(\rho)]'}{\mu_2 N^2 j_n(N\rho)[\rho h_n^{(1)}(\rho)]' - \mu_1 h_n^{(1)}(\rho)[N\rho j_n(N\rho)]'} . \tag{15}$$

At a resonance, the denominator of either a_n^t or b_n^t will be zero. A FORTRAN code was written that calculated denominator values for varying values of ρ in Eqs. (14) and (15). It was desired that such a root could be found very near the real axis, so that Real(ρ) >> Imaginary(ρ). Root searches were started by using the code to calculate the denominator values of either a_n^t or b_n^t over a range of ρ values. The coefficient type ('a' or 'b') is specified in the input file.

From this point forward, the value N in Eq. (13) will be referred to as KRATIO, as it is the ratio of the sphere material's propagation constant k_1 to the surrounding medium's propagation constant k_2. This is done in order to avoid confusion with the spherical Bessel function order N in the RES.FOR FORTRAN code, which will be described in the next section.

The program is utilized to find ρ values that correspond to a resonant combination of angular frequency (ω) and radius (a) for a given sphere material (region 1) and surrounding medium (region 2). The expression for ρ, according to Stratton [Ref. 6], is:

$$\rho = ak_2 = a\omega\sqrt{\epsilon_2\mu_2} \ . \tag{16}$$

In the code, ρ is identified by RHO_2, as it corresponds to the surrounding medium (region 2). RHO_1 (ρ_1) corresponds to the sphere material (region 1) and is given by:

$$\rho_1 = (k_1/k_2)\,\rho \ . \tag{17}$$

It was assumed that $\mu_1 = \mu_2 = \mu_0 = 4\pi\times10^{-7}$ [H·m^{-1}] and that $\varepsilon_2 = \varepsilon_0 = 8.85419\times10^{-12}$ [F·m^{-1}]. A dielectric constant (ε_r) of 5.0 was assumed for the sphere, giving the relation: $\varepsilon_1 = \varepsilon_r \cdot \varepsilon_2 = 5.0 \cdot \varepsilon_2$. Thus, ε_1 was considered to be fully real, having no imaginary part.

THE CODE (RES.FOR) DESCRIPTION AND ITS USAGE

This summary describes how to use the FORTRAN code RES.FOR. It consists of the Main Program, the SUBROUTINE SOLVE, and the SUBROUTINE NEWTON. Three output files are produced by RES. They are ITERRES.OUT, RES1.OUT, and RES2.OUT . One input file is used: RHORES.IN. A discussion of each code section and output file appears below, followed by a section describing how to use the code. Figure 3 is a flowchart summarizing the code's execution.

MAIN PROGRAM AND INPUT FILE (RHORES.IN)

The main program section of the FORTRAN code RES.FOR (Appendix A contains the full code) begins with a header, followed by an OPTIONS statement. The two options utilized are /G_FLOATING and /I4. Option /G_FLOATING was utilized in the program to allow the handling of numbers ranging approximately from 10^{-308} to 10^{+308} along both the real and imaginary axes. Option /I4 defaults all integer variables to INTEGER*4 type. All variables are initially declared as COMPLEX*16, followed by the excepting of needed INTEGER*4 and CHARACTER*1 variables with subsequent declarations.

Next the input file, RHORES.IN, to the code is OPENed and READ. Examples of the input files used to generate the needed results are found in Appendices B, C, D, and E. The strategy used in varying the values in RHORES.IN are discussed in more detail throughout the remainder of this report. DENTYP is the type of denominator being used for the Newton-Raphson iterations. In Stratton the two coefficients are a_n and b_n, so here DENTYP is a one-letter variable having either the value 'a' or 'b'. If neither 'b' nor 'B' is placed in RHORES.IN, the default is 'a'. The default IF-loop follows the READing of RHORES.IN.

NRITER is the number of Newton-Raphson iterations to be performed. MU_1, MU_2, EPS_R, and EPS_2 are as explained above. NBEG and NEND give the range of spherical Bessel function orders to be calculated. RHOMIN and RHOMAX likewise give the range of ρ values to be tried in the code, with RHODIV being the number of divisions between the minimum and maximum values. RHORES.IN is then CLOSEd, and ITERRES.OUT is OPENed. All of the input parameters are then echoed back into ITERRES.OUT. A message tells the user the name of the three output files, and then RES1.OUT and RES2.OUT are OPENed. KRATIO is then calculated. It is the ratio of k_1 to k_2, as seen earlier.

DO-loop 1100 steps through the input range of ρ (RHO_2) values. INIT stores the value of RHO_2 before Newton-Raphson recalculations. RHO_1 is found as mentioned earlier, and ITER, the current Newton-Raphson iteration, is set to 0. The DOWHILE structure is used for the iteration loop, with the condition that

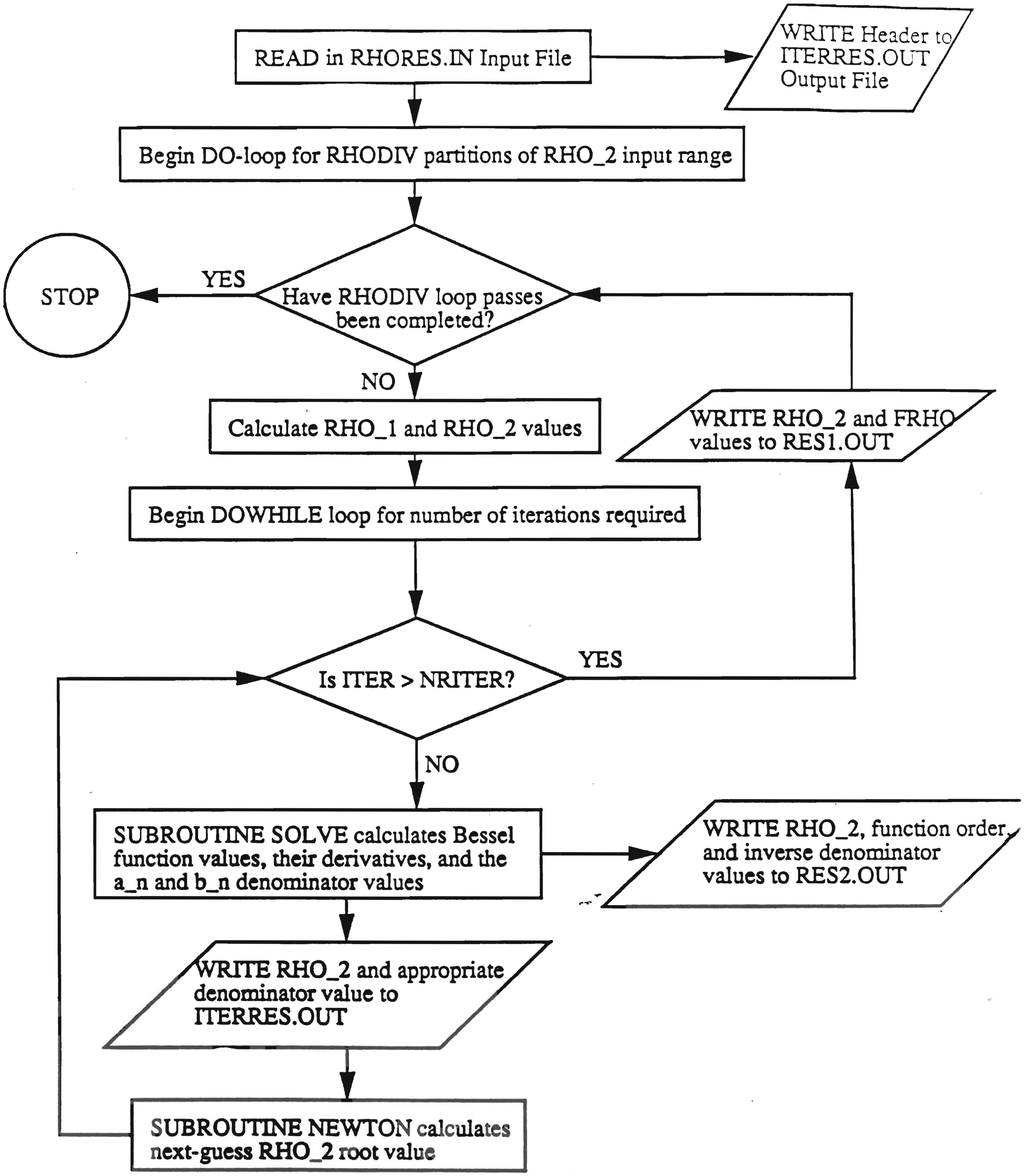

Figure 3
Flowchart for RES.FOR FORTRAN Code

ITER must be less than or equal to NRITER. The first step in the DOWHILE loop is to call the SUBROUTINE SOLVE in order to determine the denominator values of a_n (DENA) and b_n (DENB), as well as the derivatives of DENA and DENB, DENA$ and DENB$, respectively. It should be noted that '$' represents a first derivative of the variable with respect to ρ, while '$$' represents a second derivative. Depending on the type of denominator (a_n or b_n) currently being scrutinized, RHO_2 and the appropriate DEN term are written to ITERRES.OUT. Newton-Raphson is then called upon to determine the new RHO_2 value for the next iteration, passing the appropriate DEN and DEN$ values. RHO_1 is then recalculated, and ITER is stepped one.

The beginning RHO_2 value and FRHO (a function of RHO_2) are then written to RES1.OUT for the current ρ division of the 1100 DO-loop. Finally, the three output files are CLOSEd and code operations are stopped.

SUBROUTINE SOLVE

This SUBROUTINE represents the largest portion of the code. In it, the j_n and y_n spherical Bessel function values up to the needed order N are calculated. These, in turn, yield the values for DENA, DENB, DENA$, DENB$, and FRHO. Four 1-dimensional arrays are used in the calculation of the j's and y's. By having capacities of 10000, these arrays may contain j and y values up to the 9995th order. It is not a full 10000 because array indexes of 1, 2, 9999, and 10000 are required in the calculations of second derivative ($$) terms, and an N=0 index must be included. The indexes (shown in parentheses below) are offset by 3 from the true function order (N):

```
   (1) ---> N=-2
   (2) ---> N=-1
   (3) ---> N= 0
   (4) ---> N=+1
   (5) ---> N=+2
             :
             :
(9998) ---> N=+9995
```

The maximum order index (MAXORD and MAXOR2) must be offset 2 because of the needed allocation space for the N=-2 and N=-1 cases. MAXORD will never have a value less than 10, as given by the JMAX0 functions. MAXORD is the upper order limit for RHO_1-only functions, while MAXOR2 is the same for functions of RHO_2 only. The j_n's for RHO_1 (found in the array JNRHO1) and RHO_2 (array JNRHO2) are then solved as was done by Nachamkin in his program TESTJY.FOR. This is followed by the calculations of the y_n's for RHO_2 (array YNRHO2). No y_n values are needed for RHO_1 because the terms in the denominators are j_n's (spherical Bessel functions

of the 1st kind), which are functions of RHO_1 only. The $h_n^{(1)}$'s (3rd kind) are functions of RHO_2 only and are equivalent to:

$$h_n^{(1)} = j_n + iy_n \ . \tag{18}$$

Upon completion of the y_n calculations, some of the variables are initialized and the current RHO_2 value is written to RES2.OUT. DO-loop 4000 then finds all of the denominator and derivative values based on recurrence relations found in a handbook of mathematical functions [Ref. 7]. A, B, C, and CINV are used to eliminate some of the bulk in the recurrence relations and make them more readable and more easily editted. The 4000 DO-loop uses J as its counting variable, starting at 0 and going to MAXN, as found in the y_n calculations. ZERO represents the index corresponding to the actual Jth function being observed. CN and DN are the inverses of the a_n and b_n denominator values, respectively. SQCN and SQDN are simply the squares of the absolute values of CN and DN, respectively. FRHO represents the running sum of the SQCN and SQDN terms combined as the loop is passed through MAXN+1 times. SQCNTOT and SQDNTOT provide a more detailed account of the gradual accumulation of the FRHO term through the separate running summations of the SQCN and SQDN values. A special note is that the second derivatives of j_n and $h_n^{(1)}$ have been commented out because the Newton-Raphson method seemed to converge better in some cases without these terms included. This should be investigated further, however, before leaving these terms out completely. The second derivative terms are only utilized in the Newton-Raphson portion of the code, so leaving them out is not detrimental to the performance of the other portions of the code. This is not necessary a limitation of the code, but rather a possible limitation of the use of the Newton-Raphson method for functions involving spherical Bessel functions.

If the number of Newton-Raphson iterations wanted is 0 and RHO_2 is being held constant, then the current J value and all SQCN, SQDN, SQCNTOT, SQDNTOT values will be written to RES2.OUT . This will also occur if, in addition to 0 Newton-Raphson iterations being input, a single order is being scrutinized for a resonance (NBEG=NEND) and J has reached that order's value (J=NBEG=NEND).

SUBROUTINE NEWTON

In this program structure, the method of Newton-Raphson is used to attempt to converge on a root in either the a_n or b_n denominator equations, depending on which DENTYP is passed to it. A precaution has been taken to let the user know in the unlikely case that DEN$ equals (0.D0,0.D0), which immediately would kill program execution due to division by zero. After determining the new RHO_2 value, control returns to the Main Program.

OUTPUT FILE #1 (ITERRES.OUT)

See Appendix E.

OUTPUT FILE #2 (RES1.OUT)

See Appendices B and D.

OUTPUT FILE #3 (RES2.OUT)

See Appendix C.

RES.FOR CODE USAGE

Earlier work by Nachamkin [Ref. 4] had yielded possible neighborhoods of root locations along the Real axis. Thus, these prospective resonance locations were checked using the current code. It was found that the current code's findings supported Nachamkin's earlier results. The checking of the possible root locations began by inputting a range of ρ values in the neighborhood of the prospective root. The range was divided into a specified number of intervals. For each such interval, the inverse value of the denominator was determined.

The code is utilized in four ways during the determination of a root. First, a range of RHO_2 values is studied to find any FRHO peaks in that range. Second, once a peak has been chosen, the function order n giving the dominant FRHO term is determined. This also gives a clue as to whether the peak is due to a magnetic resonance (a_n approaches infinity) or an electrical resonance (b_n approaches infinity). If the dominant FRHO value comes from tbe CN term, one uses 'a' (for DENTYP) in RHORES.IN, while 'b' is used for a dominant DN term. Third, a large number of Newton-Raphson iterations is performed in order to converge upon a root RHO_2 value. A hundred or more iterations is possible. This root may or may not lie near the initial RHO_2 value which gave the peak in the FRHO function. Finally, after finding a root, the root is checked to make sure it has a dominant term for the same order n originally determined. Then the root is used in the code as the initial RHO_2 value to see if the denominator does, indeed, converge toward 0.0.

In order to understand the process better, the root identified in this study will be used as an example. The spherical Bessel function order N varies from 0 to 100, because the resonant order has not yet been determined. The real portion of RHO_2 is held constant, while the complex portion varies from -1.0 to 0.0 with 100 divisions. In Appendix B, the RES1.OUT file, one sees that the FRHO value achieves its maximum value for the -0.63 imaginary mark.

Since the peak value is now determined to two significant figures, one may determine the N value that contributes the most to FRHO, i. e., the resonant spherical Bessel function order. This is seen in Appendix C, which displays the contents of the output file used for this purpose--RES2.OUT. The RHO_2 value is held constant, while the value of N varies from 0 to 100. For N = 58, the DN value (resulting from b_n's denominator) is largest by about four orders of magnitude over all other N values. Thus, one sees that the N range may now be narrowed down to a single order, 58, for determination of the root. Also, DENTYP would be 'b' because the spike in the FRHO value results from the b_n denominator.

Having narrowed down the n value to a single order, further RHO_2 division runs are made. The final run is shown in Appendix D, which is similar to Appendix B, but now is based on one N value and is much more accurate. This time the FRHO value reaches order of magnitude 10^{29}, resulting from a complex portion of ρ equal to -0.634786707197. The full 1000 RHO_2 divisions have been narrowed down to approximately 250 divisions, located in Appendix D as well.

Finally, this root value may be checked using the RHORES.IN input file in Appendix E. Twenty iterations are calculated, with N and RHO_2 held constant. To observe the iterations of the NEWTON SUBROUTINE, the ITERRES.OUT output file is used. Appendix E also contains the resulting ITERRES.OUT file.

CONCLUSIONS AND RECOMMENDATIONS

The one major root of ρ which was identified had a value of:

$$\mathrm{REAL}(\rho) = +66.39752607619131$$
$$\mathrm{IMAGINARY}(\rho) = -0.6347867071968998 \ .$$

Thus, one may determine a possible $a\omega$ combination which would have this root value. For ρ, $\varepsilon = \varepsilon_0$ and $\mu = \mu_0$,

$$\rho = a\omega\sqrt{\varepsilon_0\mu_0} = a\omega/c \ . \tag{19}$$

In SI units, the speed of light $c = 2.99792458\times10^{8}$ [m/s]. If an a value of 10^{-6} [m] is assumed, then:

$$\omega = \frac{\rho c}{a} \approx 1.9919\times10^{16} - i\,1.9044\times10^{14}\ [rad/s] \ . \tag{20}$$

This then, is the angular frequency required within the impingent EM radiation in order to create a resonant situation. Other resonances were indicated by the outputs from the code, but this was the most prevalent one.

Of course, no complex-frequency plane waves exist. Thus, the code was used by considering only the real portion of the above root, setting the imaginary portion equal to zero. Upon doing this, however, the code became insensitive to any root in the vicinity of the root's real portion. Therefore, a number of runs looking at ranges of real-only ρ values in the ρ = 1 to 100 neighborhood were executed. The results of the ρ = 40 to 50 range are found in Figure 4, showing FRHO values versus the real portion of ρ. Possible resonances are indicated by sharp rises in the Figure 4 plot. One such resonance is detailed more closely in the Figure 5 graph, showing an approximate two order of magnitude rise over the surrounding curve region at a RHO_2 (ρ) value of approximately +43.51883 . Yet many elusive resonances surely remain, awaiting more code executions targeted along the real axis.

Much work still remains in finding more resonances and in studying other areas of the theory. A source of EM radiation having a broad enough range of frequencies to achieve resonances between two chosen spheres needs to be selected. Then, one should analyze the beat frequency produced by the interaction of the two resonant waves, as well as the effect of separation distance of the two spheres on the beat frequency. Finally, a method of rectifying this beat frequency should be established using currently available equipment, if possible. It is also important to know how much

energy is available at the resonant points. As a practical matter, manufacturing processes must be investigated that would allow structures to be fabricated with close enough tolerances to be of use.

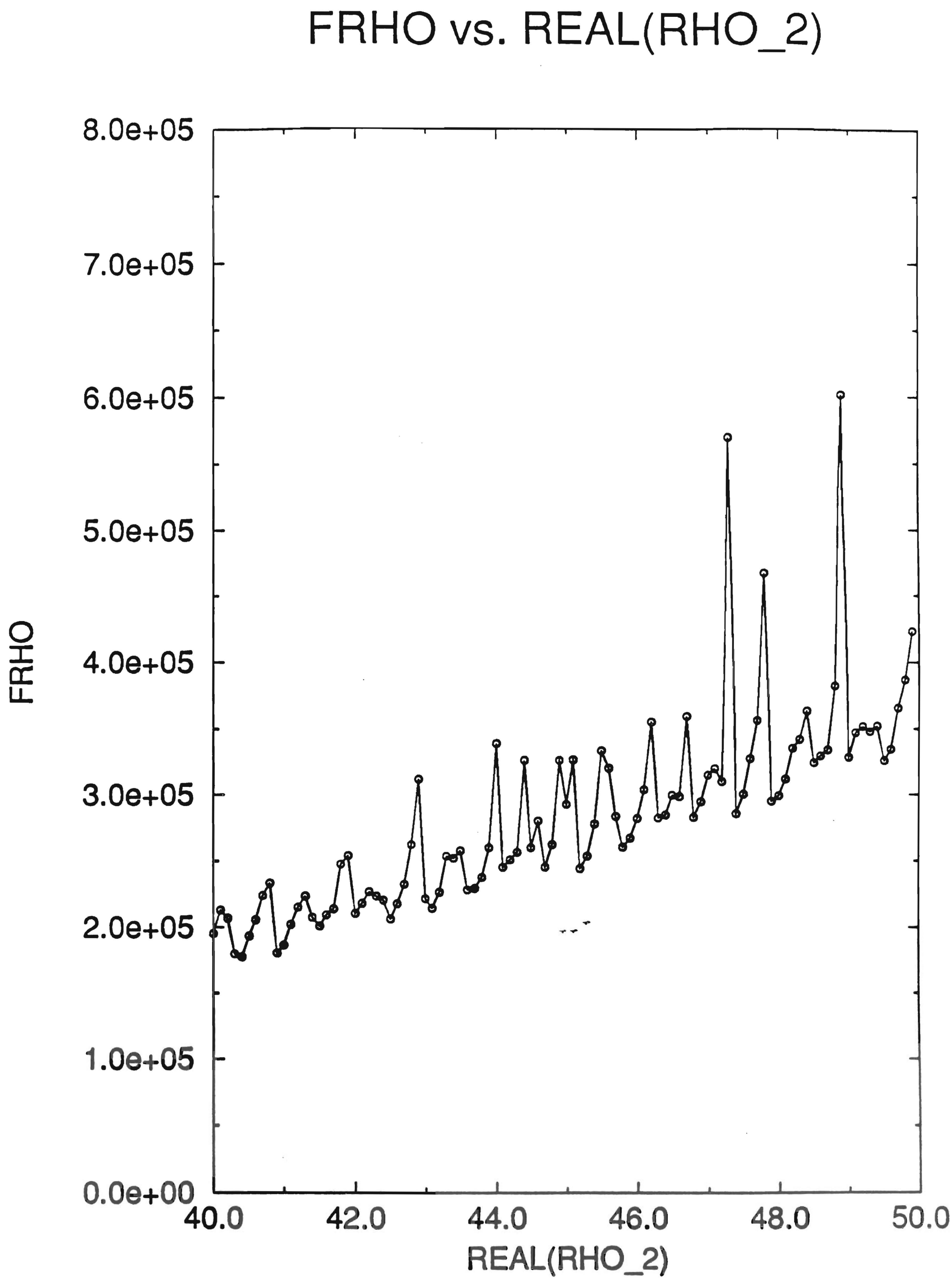

Figure 4
FRHO vs. REAL(RHO_2)

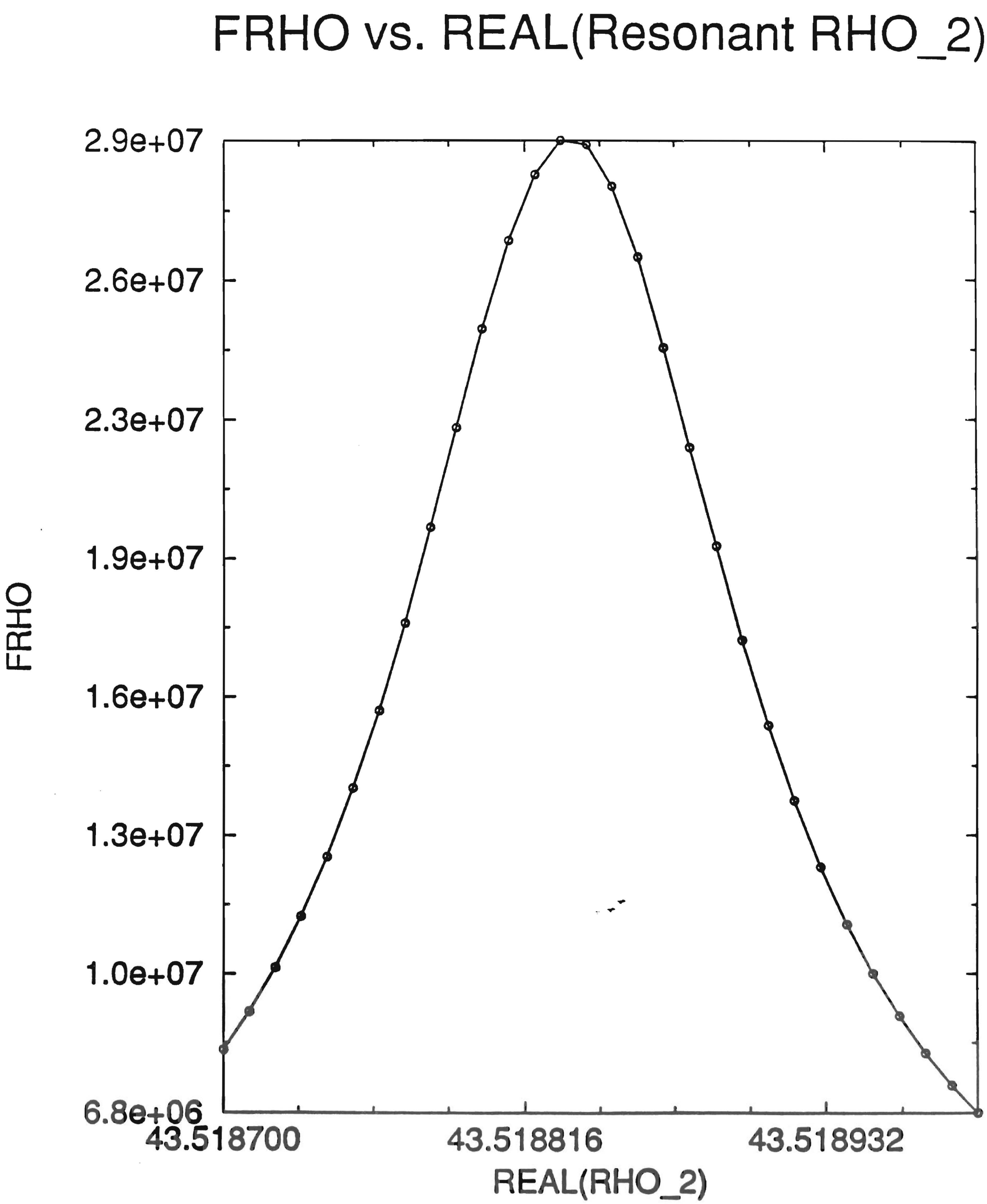

Figure 5
FRHO Around RHO_2 Resonant Value

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APPENDIX A

RES.FOR

```
C
C     PROGRAMMER:  LARRY T. COX, JR.
C     ORGANIZATION:  OLAC-PL/RKFE
C     ADDRESS:  EDWARDS AFB, CA  93523-5000
C     DATE OF ORIGIN:  4 AUGUST 1992
C     LATEST REVISION:  6 AUGUST 1992
C
      OPTIONS /G_FLOATING /I4
C23456
      PROGRAM RESONATOR

      IMPLICIT COMPLEX*16 (A-Z)

      INTEGER*4 I,ITER,J,K,L,M,N,NRITER,RHODIV,NBEG,NEND,MAXN
      CHARACTER*1 DENTYP

      OPEN (UNIT=1,FILE='RHORES.IN',FORM='FORMATTED',STATUS='OLD',
     &      ACCESS='SEQUENTIAL')
      READ (1,99) DENTYP
   99 FORMAT (A1)
      READ (1,*) NRITER  ! Number of Newton-Raphson iterations
      READ (1,*) MU_1
      READ (1,*) EPS_R
      READ (1,*) MU_2
      READ (1,*) EPS_2
      READ (1,*) NBEG  ! Function of the Nth kind
      READ (1,*) NEND  ! Function of the Nth kind
      READ (1,*) RHOMIN  ! Initial value of RHO_2
      READ (1,*) RHOMAX
      READ (1,*) RHODIV
      CLOSE (UNIT=1)
      EPS_1 = EPS_R * EPS_2

      IF (DENTYP.EQ.'B'.OR.DENTYP.EQ.'b') THEN
           DENTYP = 'b'
      ELSE
           DENTYP = 'a'
      ENDIF

      OPEN (UNIT=1,FILE='ITERRES.OUT',FORM='FORMATTED',STATUS='NEW',
     &      ACCESS='SEQUENTIAL')

      WRITE (1,*) DENTYP,'_n denominator roots'
      WRITE (1,*) 'mu_1 = ',MU_1
      WRITE (1,*) 'mu_2 = ',MU_2
      WRITE (1,*) 'epsilon_1 = ',EPS_1
      WRITE (1,*) 'epsilon_2 = ',EPS_2
      WRITE (1,*) 'Functions of the ',NBEG,'th to ',NEND,'th kind.'
```

```
      WRITE (1,*)
      WRITE (1,*) '     RE(RHO)                     ','  IM(RHO)'
      WRITE (1,*) DREAL(RHOMIN),DIMAG(RHOMIN)
      WRITE (1,*) DREAL(RHOMAX),DIMAG(RHOMAX)
      WRITE (1,*) RHODIV,' divisions'
      WRITE (1,*)
      WRITE (1,*) '        Re(rho)                  Im(rho)',
     &            '        Re(Denom ',DENTYP,'_n)   Im(Denom ',
     &            DENTYP,'_n)'
      PRINT *, 'Output file containing iterations is ITERRES.OUT  .'
      PRINT *, 'Other output files are:'
      PRINT *, 'RES1.OUT and RES2.OUT  .'

      OPEN (UNIT=2,FILE='RES1.OUT',FORM='FORMATTED',STATUS='NEW',
     &      ACCESS='SEQUENTIAL')
      OPEN (UNIT=3,FILE='RES2.OUT',FORM='FORMATTED',STATUS='NEW',
     &      ACCESS='SEQUENTIAL')
      KRATIO = CDSQRT(MU_1*EPS_1 / (MU_2*EPS_2))
      WRITE (2,*) 'Rho''s with Functions of Rho''s'

      DO 1100 L = 1,RHODIV
           RHO_2 = RHOMIN + DCMPLX(L-1)*(RHOMAX-RHOMIN)/DCMPLX(RHODIV)
           INIT = RHO_2
           RHO_1 = KRATIO * RHO_2
           ITER = 0

           DOWHILE (ITER.LE.NRITER)
                CALL SOLVE(KRATIO,RHO_1,RHO_2,DENA,DENA$,N,RHODIV,
     &                     MU_1,MU_2,DENB,DENB$,NBEG,NEND,FRHO,NRITER)

                IF (DENTYP.EQ.'b') THEN
                     WRITE (1,1095) RHO_2,DENB
                ELSE
                     WRITE (1,1095) RHO_2,DENA
                ENDIF

1095            FORMAT (2E24.16,2E16.8)

                IF (DENTYP.EQ.'b') THEN
                     CALL NEWTON(ITER,NRITER,DENB,DENB$,RHO_2)
                ELSE
                     CALL NEWTON(ITER,NRITER,DENA,DENA$,RHO_2)
                ENDIF

                RHO_1 = KRATIO * RHO_2
                ITER = ITER + 1
           ENDDO

1098       FORMAT (5E16.8)
           WRITE (2,1099) INIT,FRHO
1099       FORMAT (E24.16,E24.16,E24.16,E8.2)
           WRITE (1,*)
```

```
 1100 CONTINUE

      CLOSE (UNIT=1)
      CLOSE (UNIT=2)
      CLOSE (UNIT=3)

      STOP
      END

C======================================================================
C23456
      OPTIONS /G_FLOATING /I4

      SUBROUTINE SOLVE(KRATIO,RHO_1,RHO_2,DENA,DENA$,N,RHODIV,
     &                 MU_1,MU_2,DENB,DENB$,NBEG,NEND,FRHO,NRITER)

      IMPLICIT COMPLEX*16 (A-Z)

      INTEGER*4 I,IORD,J,K,L,M,MAXORD,MAXOR2,N,ORDER,RHODIV,ZERO
      INTEGER*4 NBEG,NEND,MAXN,NRITER
      REAL*8 SQCN,SQDN,A,B,C,CINV,SQCNTOT,SQDNTOT
      COMPLEX*16 JNRHO1(10000),JNRHO2(10000),YNRHO2(10000)
      COMPLEX*16 H1NRHO2(10000)

      DATA JNRHO1 /10000 * (0.D0,0.D0)/
      DATA JNRHO2 /10000 * (0.D0,0.D0)/
      DATA YNRHO2 /10000 * (0.D0,0.D0)/
      DATA H1NRHO2 /10000 * (0.D0,0.D0)/

      ORDER = NEND+1
      MAXORD = 2 + JIDINT(DREAL(RHO_1)) +
     &         JIDINT(DREAL(CDSQRT((150.D0,0.D0)*RHO_1)))
      MAXORD = JMAX0(MAXORD,10)
      MAXOR2 = 2 + JIDINT(DREAL(RHO_2)) +
     &         JIDINT(DREAL(CDSQRT((150.D0,0.D0)*RHO_2)))
      MAXOR2 = JMAX0(MAXOR2,10)

      IF (MAXORD.GT.9999) THEN
           PRINT *, ' RHO_1 TOO BIG !!! (= ',DREAL(RHO_1),')'
           STOP
      ELSEIF (MAXOR2.GT.9999) THEN
           PRINT *, ' RHO_2 TOO BIG !!! (= ',DREAL(RHO_2),')'
           STOP
      ENDIF
C
C Begin the jn's for RHO_1
C
      RHO1INV = (1.D0,0.D0)/RHO_1
      RHO12IN = RHO1INV + RHO1INV

      B1 = -RHO1INV - RHO12IN
      JNRHO1(1) = -CDCOS(RHO_1)/RHO_1**2 - CDSIN(RHO_1)/RHO_1
```

```
      JNRHO1(2) = CDCOS(RHO_1)/RHO_1
      R10 = -CDSIN(RHO_1)/RHO_1
      R11 = (R10+CDCOS(RHO_1))*RHO1INV
      BETA1 = B1
      JNRHO1(3) = R10/BETA1

      IORD = 4
      B1 = B1 - RHO12IN
      YNRHO2(IORD) = (1.D0,0.D0)/BETA1
      BETA1 = B1
      JNRHO1(IORD) = R11/BETA1

      DO 2000 IORD = 5,MAXORD+4
            B1 = B1 - RHO12IN
            YNRHO2(IORD) = (1.D0,0.D0)/BETA1
            BETA1 = B1 - YNRHO2(IORD)
            JNRHO1(IORD) = -JNRHO1(IORD-1)/BETA1
 2000 CONTINUE

      DO 2100 IORD = MAXORD+3,3,-1
            JNRHO1(IORD) = JNRHO1(IORD)-YNRHO2(IORD+1)*JNRHO1(IORD+1)
 2100 CONTINUE

      DO 2200 IORD = MAXORD+3,3,-1
            JNRHO1(IORD+1) = JNRHO1(IORD)
 2200 CONTINUE

      JNRHO1(3) = -R10
C
C Begin the jn's for RHO_2
C
      RHO2INV = (1.D0,0.D0)/RHO_2
      RHO22IN = RHO2INV + RHO2INV

      B2 = -RHO2INV - RHO22IN
      JNRHO2(1) = -CDCOS(RHO_2)/RHO_2**2 - CDSIN(RHO_2)/RHO_2
      JNRHO2(2) = CDCOS(RHO_2)/RHO_2
      R20 = -CDSIN(RHO_2)/RHO_2
      R21 = (R20+CDCOS(RHO_2))*RHO2INV
      BETA2 = B2
      JNRHO2(3) = R20/BETA2

      IORD = 4
      B2 = B2 - RHO22IN
      YNRHO2(IORD) = (1.D0,0.D0)/BETA2
      BETA2 = B2
      JNRHO2(IORD) = R21/BETA2

      DO 2300 IORD = 5,MAXOR2+4
            B2 = B2 - RHO22IN
            YNRHO2(IORD) = (1.D0,0.D0)/BETA2
            BETA2 = B2 - YNRHO2(IORD)
```

```
          JNRHO2(IORD) = -JNRHO2(IORD-1)/BETA2
 2300 CONTINUE

      DO 2400 IORD = MAXOR2+3,3,-1
          JNRHO2(IORD) = JNRHO2(IORD)-YNRHO2(IORD+1)*JNRHO2(IORD+1)
 2400 CONTINUE

      DO 2500 IORD = MAXOR2+3,3,-1
          JNRHO2(IORD+1) = JNRHO2(IORD)
 2500 CONTINUE

      JNRHO2(3) = -R20
C
C Begin the yn's for RHO_2
C
      YNRHO2(1) = -JNRHO2(4)
      YNRHO2(2) = JNRHO2(3)
      YNRHO2(3) = -CDCOS(RHO_2) / RHO_2
      YNRHO2(4) = -JNRHO2(3) + YNRHO2(3) / RHO_2
      IORD = 4
      TN2 = RHO2INV
      TN2P = (1.D0,0.D0)

      IF (NEND.GT.MAXORD) THEN
          MAXN = MAXORD
      ELSE
          MAXN = NEND
      ENDIF

      DOWHILE (IORD.LE.(MAXORD+4))
          IORD = IORD+1
          TN2 = TN2 + RHO22IN
          YNRHO2(IORD) = TN2*YNRHO2(IORD-1) - YNRHO2(IORD-2)
          TN2P = TN2 + RHO22IN
      ENDDO

      DO 3000 I = 1,MAXORD+4
          H1NRHO2(I) = JNRHO2(I) + (0.D0,1.D0)*YNRHO2(I)
 3000 CONTINUE

      ONE = (1.D0,0.D0)
      TWO = (2.D0,0.D0)
      FRHO = (0.D0,0.D0)
      SQCNTOT = 0.D0
      SQDNTOT = 0.D0
      WRITE (3,*) 'RHO = ',RHO_2

      DO 4000 J = 0,MAXN
          A = DFLOAT(J)
          B = A + 1.D0
          C = 2.D0*A + 1.D0
          CINV = 1.D0 / C
```

```
                ZERO = J+3
                JN = JNRHO1(ZERO)
                JN$ = (A*JNRHO1(ZERO-1) - B*JNRHO1(ZERO+1)) * CINV
                JNM1$ = (A*JNRHO1(ZERO-2) - B*JN) * CINV
                JNP1$ = (A*JN - B*JNRHO1(ZERO+2)) * CINV
                H1N = H1NRHO2(ZERO)
                H1N$ = (A*H1NRHO2(ZERO-1) - B*H1NRHO2(ZERO+1)) * CINV
                H1NM1$ = (A*H1NRHO2(ZERO-2) - B*H1N) * CINV
                H1NP1$ = (A*H1N - B*H1NRHO2(ZERO+2)) * CINV

C                JN$$ = (A*JNM1$ - B*JNP1$) * CINV
C                H1N$$ = (A*H1NM1$ - B*H1NP1$) * CINV

                DENA = - H1N * (RHO_1*JN$+JN)
     &                 + JN * (RHO_2*H1N$+H1N)
                DENA$ = + JN*(RHO_2*H1N$$+2.D0*H1N$) + JN$*(RHO_2*H1N$+H1N)
     &                  - H1N*(RHO_1*JN$$+2.D0*JN$)
     &                  - H1N$*(RHO_1*JN$+JN)
                DENB = + H1N * (RHO_1*JN$+JN)
     &                 - KRATIO**2*JN * (RHO_2*H1N$+H1N)
                DENB$ = + H1N*(RHO_1*JN$$+2.D0*JN$)
     &                  + H1N$*(RHO_1*JN$+JN)
     &                  - KRATIO**2*JN*(RHO_2*H1N$$+2.D0*H1N$)
     &                  - KRATIO**2*JN$*(RHO_2*H1N$+H1N)
                CN = ONE / DENA
                DN = ONE / DENB
                SQCN = (DREAL(CN))**2 + (DIMAG(CN))**2
                SQDN = (DREAL(DN))**2 + (DIMAG(DN))**2
                FRHO = FRHO + SQCN + SQDN
                SQCNTOT = SQCNTOT + SQCN
                SQDNTOT = SQDNTOT + SQDN

                IF (NRITER.EQ.0.AND.RHODIV.EQ.1) THEN
                     WRITE (3,*) 'ORDER = ',J
                     WRITE (3,3995) SQCN,SQCNTOT,SQDN,SQDNTOT
                ELSEIF (NBEG.EQ.NEND.AND.J.EQ.NEND.AND.NRITER.EQ.0) THEN
                     WRITE (3,*) 'ORDER = ',J
                     WRITE (3,3995) SQCN,SQCNTOT,SQDN,SQDNTOT
                     WRITE (3,*)
                ENDIF

 3995           FORMAT (4G20.10)
 4000 CONTINUE

      RETURN
      END

C===========================================================================
C23456
      OPTIONS /G_FLOATING /I4

      SUBROUTINE NEWTON(ITER,NRITER,DEN,DEN$,RHO_2)
```

26

```
      IMPLICIT COMPLEX*16 (A-Z)

      INTEGER*4 ITER,NRITER

      IF (DEN$.EQ.(0.D0,0.D0)) THEN
           ITER = NRITER
           WRITE (1,5097) 'DEN$=(0.D0,0.D0)'
5097       FORMAT (A)
      ELSE
           DELRHO = -DEN / DEN$
           RHO_2 = RHO_2 + DELRHO
      ENDIF

      RETURN
      END
```

APPENDIX B

RHORES.IN and RES1.OUT (1st run)

```
b
0
(1.25663706144D-6,0.D0)
(5.D0,0.D0)
(1.25663706144D-6,0.D0)
(8.85418782D-12,0.D0)
0
100
(66.3975260761913D0,-1.D0)
(66.3975260761913D0,0.D0)
100
```

Rho's with Functions of Rho's

0.6639752607619130E+02	-0.10000000E+01	0.5832946019812745E+05	0.0000E+00
0.6639752607619130E+02	-0.99000000E+00	0.5942798842887465E+05	0.0000E+00
0.6639752607619130E+02	-0.98000000E+00	0.6065642728623391E+05	0.0000E+00
0.6639752607619130E+02	-0.97000000E+00	0.6202102098364594E+05	0.0000E+00
0.6639752607619130E+02	-0.96000000E+00	0.6352919605634567E+05	0.0000E+00
0.6639752607619130E+02	-0.95000000E+00	0.6518974139281166E+05	0.0000E+00
0.6639752607619130E+02	-0.94000000E+00	0.6701302511900682E+05	0.0000E+00
0.6639752607619130E+02	-0.93000000E+00	0.6901125835360250E+05	0.0000E+00
0.6639752607619130E+02	-0.92000000E+00	0.7119881849116909E+05	0.0000E+00
0.6639752607619130E+02	-0.91000000E+00	0.7359264829137213E+05	0.0000E+00
0.6639752607619130E+02	-0.90000000E+00	0.7621275203192639E+05	0.0000E+00
0.6639752607619130E+02	-0.89000000E+00	0.7908281686893944E+05	0.0000E+00
0.6639752607619130E+02	-0.88000000E+00	0.8223099716105772E+05	0.0000E+00
0.6639752607619130E+02	-0.87000000E+00	0.8569091309061948E+05	0.0000E+00
0.6639752607619130E+02	-0.86000000E+00	0.8950293435562658E+05	0.0000E+00
0.6639752607619130E+02	-0.85000000E+00	0.9371584798417194E+05	0.0000E+00
0.6639752607619130E+02	-0.84000000E+00	0.9838905117578449E+05	0.0000E+00
0.6639752607619130E+02	-0.83000000E+00	0.1035954732316571E+06	0.0000E+00
0.6639752607619130E+02	-0.82000000E+00	0.1094255279987954E+06	0.0000E+00
0.6639752607619130E+02	-0.81000000E+00	0.1159925519140877E+06	0.0000E+00
0.6639752607619130E+02	-0.80000000E+00	0.1234404315763505E+06	0.0000E+00
0.6639752607619130E+02	-0.79000000E+00	0.1319545392892882E+06	0.0000E+00
0.6639752607619130E+02	-0.78000000E+00	0.1417778071454112E+06	0.0000E+00
0.6639752607619130E+02	-0.77000000E+00	0.1532350356617195E+06	0.0000E+00
0.6639752607619130E+02	-0.76000000E+00	0.1667708665727319E+06	0.0000E+00
0.6639752607619130E+02	-0.75000000E+00	0.1830113327824183E+06	0.0000E+00
0.6639752607619130E+02	-0.74000000E+00	0.2028679161262282E+06	0.0000E+00
0.6639752607619130E+02	-0.73000000E+00	0.2277221518793277E+06	0.0000E+00
0.6639752607619130E+02	-0.72000000E+00	0.2597718390884264E+06	0.0000E+00
0.6639752607619130E+02	-0.71000000E+00	0.3027240302222338E+06	0.0000E+00
0.6639752607619130E+02	-0.70000000E+00	0.3632952876402438E+06	0.0000E+00
0.6639752607619130E+02	-0.69000000E+00	0.4547938649770824E+06	0.0000E+00
0.6639752607619130E+02	-0.68000000E+00	0.6068445954717640E+06	0.0000E+00
0.6639752607619130E+02	-0.67000000E+00	0.8969560608025888E+06	0.0000E+00
0.6639752607619130E+02	-0.66000000E+00	0.1584843084218144E+07	0.0000E+00
0.6639752607619130E+02	-0.65000000E+00	0.4032547676841964E+07	0.0000E+00
0.6639752607619130E+02	-0.64000000E+00	0.3299221352934197E+08	0.0000E+00
0.6639752607619130E+02	-0.63000000E+00	0.3945092293223719E+08	0.0000E+00
0.6639752607619130E+02	-0.62000000E+00	0.4389945914409366E+07	0.0000E+00
0.6639752607619130E+02	-0.61000000E+00	0.1737334773076357E+07	0.0000E+00
0.6639752607619130E+02	-0.60000000E+00	0.1014707913437646E+07	0.0000E+00
0.6639752607619130E+02	-0.59000000E+00	0.7189526088705342E+06	0.0000E+00
0.6639752607619130E+02	-0.58000000E+00	0.5700357159533311E+06	0.0000E+00
0.6639752607619130E+02	-0.57000000E+00	0.4852838429767232E+06	0.0000E+00
0.6639752607619130E+02	-0.56000000E+00	0.4333653036170878E+06	0.0000E+00
0.6639752607619130E+02	-0.55000000E+00	0.4003407547898380E+06	0.0000E+00
0.6639752607619130E+02	-0.54000000E+00	0.3792618208541028E+06	0.0000E+00
0.6639752607619130E+02	-0.53000000E+00	0.3663566904123807E+06	0.0000E+00
0.6639752607619130E+02	-0.52000000E+00	0.3594433543536134E+06	0.0000E+00
0.6639752607619130E+02	-0.51000000E+00	0.3572059996408999E+06	0.0000E+00
0.6639752607619130E+02	-0.50000000E+00	0.3588425746327236E+06	0.0000E+00
0.6639752607619130E+02	-0.49000000E+00	0.3638867262380186E+06	0.0000E+00
0.6639752607619130E+02	-0.48000000E+00	0.3721195131488260E+06	0.0000E+00
0.6639752607619130E+02	-0.47000000E+00	0.3835335354846214E+06	0.0000E+00
0.6639752607619130E+02	-0.46000000E+00	0.3983345162081381E+06	0.0000E+00
0.6639752607619130E+02	-0.45000000E+00	0.4169781477992669E+06	0.0000E+00
0.6639752607619130E+02	-0.44000000E+00	0.4402492810730193E+06	0.0000E+00
0.6639752607619130E+02	-0.43000000E+00	0.4693969889513739E+06	0.0000E+00
0.6639752607619130E+02	-0.42000000E+00	0.5063328348086139E+06	0.0000E+00
0.6639752607619130E+02	-0.41000000E+00	0.5538348649144967E+06	0.0000E+00
0.6639752607619130E+02	-0.40000000E+00	0.6154173400618308E+06	0.0000E+00
0.6639752607619130E+02	-0.39000000E+00	0.6936720638097440E+06	0.0000E+00
0.6639752607619130E+02	-0.38000000E+00	0.7848578292114019E+06	0.0000E+00

0.6639752607619130E+02	-0.37000000E+00	0.8727333989984004E+06	0.0000E+00
0.6639752607619130E+02	-0.36000000E+00	0.9427755439230207E+06	0.0000E+00
0.6639752607619130E+02	-0.35000000E+00	0.1019815082250440E+07	0.0000E+00
0.6639752607619130E+02	-0.34000000E+00	0.1192427868293669E+07	0.0000E+00
0.6639752607619130E+02	-0.33000000E+00	0.1778014929311780E+07	0.0000E+00
0.6639752607619130E+02	-0.32000000E+00	0.6090784934672905E+07	0.0000E+00
0.6639752607619130E+02	-0.31000000E+00	0.8699783983438948E+07	0.0000E+00
0.6639752607619130E+02	-0.30000000E+00	0.2214935990570053E+07	0.0000E+00
0.6639752607619130E+02	-0.29000000E+00	0.1596113394360710E+07	0.0000E+00
0.6639752607619130E+02	-0.28000000E+00	0.1525215336211312E+07	0.0000E+00
0.6639752607619130E+02	-0.27000000E+00	0.1607614311235852E+07	0.0000E+00
0.6639752607619130E+02	-0.26000000E+00	0.1793873295695752E+07	0.0000E+00
0.6639752607619130E+02	-0.25000000E+00	0.2104183966867282E+07	0.0000E+00
0.6639752607619130E+02	-0.24000000E+00	0.2523179777238031E+07	0.0000E+00
0.6639752607619130E+02	-0.23000000E+00	0.2940400301811221E+07	0.0000E+00
0.6639752607619130E+02	-0.22000000E+00	0.3354138243385256E+07	0.0000E+00
0.6639752607619130E+02	-0.21000000E+00	0.3502321774989490E+07	0.0000E+00
0.6639752607619130E+02	-0.20000000E+00	0.3142732036521640E+07	0.0000E+00
0.6639752607619130E+02	-0.19000000E+00	0.2690614618297547E+07	0.0000E+00
0.6639752607619130E+02	-0.18000000E+00	0.2385647544437100E+07	0.0000E+00
0.6639752607619130E+02	-0.17000000E+00	0.2212265301879473E+07	0.0000E+00
0.6639752607619130E+02	-0.16000000E+00	0.2132126019325340E+07	0.0000E+00
0.6639752607619130E+02	-0.15000000E+00	0.2114527588065502E+07	0.0000E+00
0.6639752607619130E+02	-0.14000000E+00	0.2111049172969458E+07	0.0000E+00
0.6639752607619130E+02	-0.13000000E+00	0.2072979041079385E+07	0.0000E+00
0.6639752607619130E+02	-0.12000000E+00	0.2038270863269938E+07	0.0000E+00
0.6639752607619130E+02	-0.11000000E+00	0.2180590848089927E+07	0.0000E+00
0.6639752607619130E+02	-0.10000000E+00	0.3064759482032674E+07	0.0000E+00
0.6639752607619130E+02	-0.90000000E-01	0.7261293817461066E+07	0.0000E+00
0.6639752607619130E+02	-0.80000000E-01	0.5315399848594837E+07	0.0000E+00
0.6639752607619130E+02	-0.70000000E-01	0.2339974279059302E+07	0.0000E+00
0.6639752607619130E+02	-0.60000000E-01	0.1602618136046374E+07	0.0000E+00
0.6639752607619130E+02	-0.50000000E-01	0.1422342783974448E+07	0.0000E+00
0.6639752607619130E+02	-0.40000000E-01	0.3426647341610848E+07	0.0000E+00
0.6639752607619130E+02	-0.30000000E-01	0.1883807543007345E+07	0.0000E+00
0.6639752607619130E+02	-0.20000000E-01	0.1036305339370152E+07	0.0000E+00
0.6639752607619130E+02	-0.10000000E-01	0.8958218026219722E+06	0.0000E+00

APPENDIX C

RHORES.IN and RES2.OUT

```
b
0
(1.25663706144D-6,0.D0)
(5.D0,0.D0)
(1.25663706144D-6,0.D0)
(8.85418782D-12,0.D0)
0
100
(66.3975260761913D0,-.63D0)
(66.3975260761913D0,-.63D0)
1
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RHO = (66.3975260761913,-0.630000000000000)

ORDER =	0			
972.2248651		972.2248651	187.6500753	187.6500753
ORDER =	1			
934.4283634		1906.653228	195.4329582	383.0830335
ORDER =	2			
984.3801688		2891.033397	185.8901814	568.9732149
ORDER =	3			
915.8408388		3806.874236	200.4964131	769.4696280
ORDER =	4			
1013.711925		4820.586161	181.9734826	951.4431106
ORDER =	5			
884.6268189		5705.212979	210.1082728	1161.551383
ORDER =	6			
1062.136542		6767.349522	176.3922360	1337.943619
ORDER =	7			
844.7351624		7612.084684	224.9893403	1562.932960
ORDER =	8			
1131.011708		8743.096392	169.9882173	1732.921177
ORDER =	9			
801.8185456		9544.914937	245.6614577	1978.582635
ORDER =	10			
1217.253981		10762.16892	163.9662347	2142.548869
ORDER =	11			
762.8165370		11524.98546	271.1924904	2413.741360
ORDER =	12			
1305.358288		12830.34374	159.8700718	2573.611432
ORDER =	13			
735.4863637		13565.83011	296.6414655	2870.252897
ORDER =	14			
1358.412309		14924.24242	159.6115646	3029.864462
ORDER =	15			
728.4198871		15652.66230	310.9098915	3340.774353
ORDER =	16			
1327.425915		16980.08822	165.7111766	3506.485530
ORDER =	17			
752.0057504		17732.09397	302.0255827	3808.511113
ORDER =	18			
1197.332567		18929.42654	181.9250964	3990.436209
ORDER =	19			
820.1300882		19749.55662	271.0676079	4261.503817
ORDER =	20			
1017.080151		20766.63677	214.2704989	4475.774316
ORDER =	21			
949.4312538		21716.06803	233.8585674	4709.632883
ORDER =	22			
854.9080545		22570.97608	270.9072201	4980.540103
ORDER =	23			
1140.459325		23711.43541	205.9048081	5186.444911
ORDER =	24			
750.1737200		24461.60913	351.0899253	5537.534837
ORDER =	25			
1307.770698		25769.37983	195.5022884	5733.037125
ORDER =	26			
717.6688645		26487.04869	406.8593350	6139.896460
ORDER =	27			
1264.348619		27751.39731	209.2200640	6349.116524
ORDER =	28			
771.3806371		28522.77795	371.4091562	6720.525680
ORDER =	29			
1024.466302		29547.24425	260.8257408	6981.351421
ORDER =	30			
935.7814954		30483.02574	295.8745499	7277.225971
ORDER =	31			

806.5009321		31289.52668	377.0388154	7654.264786
ORDER =	32			
1187.219276		32476.74595	251.2729102	7905.537696
ORDER =	33			
707.3269736		33184.07293	535.0537958	8440.591492
ORDER =	34			
1257.312913		34441.38584	257.4043703	8697.995862
ORDER =	35			
741.1712328		35182.55707	517.8036111	9215.799473
ORDER =	36			
993.8564614		36176.41353	339.7936620	9555.593135
ORDER =	37			
931.8798625		37108.29340	381.5471477	9937.140283
ORDER =	38			
752.3541347		37860.64753	572.7077589	10509.84804
ORDER =	39			
1196.983720		39057.63125	324.2430500	10834.09109
ORDER =	40			
684.0315444		39741.66279	824.7602214	11658.85131
ORDER =	41			
1095.362600		40837.02539	384.2368843	12043.08820
ORDER =	42			
802.9128895		41639.93828	613.8301144	12656.91831
ORDER =	43			
783.3037057		42423.24199	685.2079883	13342.12630
ORDER =	44			
1084.661147		43507.90314	455.9571781	13798.08348
ORDER =	45			
656.6129334		44164.51607	1334.284575	15132.36805
ORDER =	46			
1065.854660		45230.37073	526.9875837	15659.35564
ORDER =	47			
752.4465220		45982.81725	980.8526343	16640.20827
ORDER =	48			
741.0281641		46723.84542	1111.912906	17752.12118
ORDER =	49			
1024.268083		47748.11350	687.2612845	18439.38246
ORDER =	50			
619.8824995		48367.99600	2816.917682	21256.30014
ORDER =	51			
933.2215920		49301.21759	933.4278782	22189.72802
ORDER =	52			
746.7748971		50047.99249	1563.762956	23753.49098
ORDER =	53			
633.1649123		50681.15740	3453.033284	27206.52426
ORDER =	54			
958.2016636		51639.35906	1281.035856	28487.56012
ORDER =	55			
582.4799094		52221.83897	7948.997769	36436.55789
ORDER =	56			
707.8216956		52929.66067	3371.731383	39808.28927
ORDER =	57			
760.9429371		53690.60360	3126.318710	42934.60798
ORDER =	58			
509.7821808		54200.38579	39212540.21	39255474.82
ORDER =	59			
735.8181638		54936.20395	7248.565280	39262723.38
ORDER =	60			
558.5152406		55494.71919	9834.353822	39272557.73
ORDER =	61			
462.4843988		55957.20359	12355.77148	39284913.51
ORDER =	62			
630.7404790		56587.94407	99562.87663	39384476.38
ORDER =	63			
398.3959575		56986.34002	2346.981242	39386823.36

ORDER = 64			
383.0784337	57369.41846	2331.385413	39389154.75
ORDER = 65			
420.5474146	57789.96587	1763.133344	39390917.88
ORDER = 66			
245.2046028	58035.17048	470.7230732	39391388.61
ORDER = 67			
235.8824654	58271.05294	441.9821828	39391830.59
ORDER = 68			
187.5687740	58458.62172	197.3234042	39392027.91
ORDER = 69			
96.42096173	58555.04268	88.53890809	39392116.45
ORDER = 70			
77.08895275	58632.13163	60.67678287	39392177.13
ORDER = 71			
41.11082041	58673.24245	21.31919876	39392198.45
ORDER = 72			
17.01825856	58690.26071	10.13661601	39392208.58
ORDER = 73			
10.48916236	58700.74987	4.949877259	39392213.53
ORDER = 74			
3.979771329	58704.72964	1.429882639	39392214.96
ORDER = 75			
1.338944808	58706.06859	0.6163998092	39392215.58
ORDER = 76			
0.6696262256	58706.73821	0.2336347882	39392215.81
ORDER = 77			
0.2039898478	58706.94220	0.5703041639E-01	39392215.87
ORDER = 78			
0.5706777265E-01	58706.99927	0.2140896778E-01	39392215.89
ORDER = 79			
0.2417996204E-01	58707.02345	0.6943875875E-02	39392215.90
ORDER = 80			
0.6470666331E-02	58707.02992	0.1448718199E-02	39392215.90
ORDER = 81			
0.1500585757E-02	58707.03142	0.4632894529E-03	39392215.90
ORDER = 82			
0.5436122764E-03	58707.03197	0.1393918747E-03	39392215.90
ORDER = 83			
0.1382514275E-03	58707.03210	0.2511985089E-04	39392215.90
ORDER = 84			
0.2642533004E-04	58707.03213	0.6616063731E-05	39392215.90
ORDER = 85			
0.7976083188E-05	58707.03214	0.1948834333E-05	39392215.90
ORDER = 86			
0.2077497211E-05	58707.03214	0.3166628450E-06	39392215.90
ORDER = 87			
0.3344830613E-06	58707.03214	0.6563098797E-07	39392215.90
ORDER = 88			
0.7956812163E-07	58707.03214	0.1875309857E-07	39392215.90
ORDER = 89			
0.2183178614E-07	58707.03214	0.3067539013E-08	39392215.90
ORDER = 90			
0.3255914900E-08	58707.03214	0.4838736526E-09	39392215.90
ORDER = 91			
0.5763290314E-09	58707.03214	0.1205394753E-09	39392215.90
ORDER = 92			
0.1515927923E-09	58707.03214	0.2319829132E-10	39392215.90
ORDER = 93			
0.2542666128E-10	58707.03214	0.2896975372E-11	39392215.90
ORDER = 94			
0.3342033362E-11	58707.03214	0.5388991059E-12	39392215.90
ORDER = 95			
0.6909957503E-12	58707.03214	0.1232142292E-12	39392215.90
ORDER = 96			

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   0.1482734719E-12      58707.03214        0.1530812715E-13      39392215.90
ORDER =            97
   0.1722497837E-13      58707.03214        0.1948378647E-14      39392215.90
ORDER =            98
   0.2411439458E-14      58707.03214        0.3921698957E-15      39392215.90
ORDER =            99
   0.5155239694E-15      58707.03214        0.6821199916E-16      39392215.90
ORDER =           100
   0.7977617019E-16      58707.03214        0.6797385709E-17      39392215.90
```

APPENDIX D

RHORES.IN and RES1.OUT (2nd run)

```
b
0
(1.25663706144D-6,0.D0)
(5.D0,0.D0)
(1.25663706144D-6,0.D0)
(8.85418782D-12,0.D0)
58
58
(66.3975260761913D0,-.634786707D0)
(66.3975260761913D0,-.634786708D0)
1000
```

Rho's with Functions of Rho's

:

:

0.6639752607619130E+02	-0.6347867071019999E+00	0.9929602783900407E+230.00E+00
0.6639752607619130E+02	-0.6347867071030000E+00	0.1014410959638363E+240.00E+00
0.6639752607619130E+02	-0.6347867071040000E+00	0.1036347260235330E+240.00E+00
0.6639752607619130E+02	-0.6347867071050000E+00	0.1059242052408832E+240.00E+00
0.6639752607619130E+02	-0.6347867071059999E+00	0.1082871584885779E+240.00E+00
0.6639752607619130E+02	-0.6347867071069999E+00	0.1105445852407965E+240.00E+00
0.6639752607619130E+02	-0.6347867071080000E+00	0.1130487245893498E+240.00E+00
0.6639752607619130E+02	-0.6347867071090000E+00	0.1156718772688488E+240.00E+00
0.6639752607619130E+02	-0.6347867071100000E+00	0.1183621657208496E+240.00E+00
0.6639752607619130E+02	-0.6347867071109999E+00	0.1211302275900983E+240.00E+00
0.6639752607619130E+02	-0.6347867071119999E+00	0.1240279174983865E+240.00E+00
0.6639752607619130E+02	-0.6347867071130000E+00	0.1270096260587070E+240.00E+00
0.6639752607619130E+02	-0.6347867071140000E+00	0.1300324712146113E+240.00E+00
0.6639752607619130E+02	-0.6347867071150000E+00	0.1332135243075332E+240.00E+00
0.6639752607619130E+02	-0.6347867071159999E+00	0.1365576432486391E+240.00E+00
0.6639752607619130E+02	-0.6347867071169999E+00	0.1399561142546825E+240.00E+00
0.6639752607619130E+02	-0.6347867071180000E+00	0.1435776620485633E+240.00E+00
0.6639752607619130E+02	-0.6347867071190000E+00	0.1472880608866953E+240.00E+00
0.6639752607619130E+02	-0.6347867071200000E+00	0.1511678389003229E+240.00E+00
0.6639752607619130E+02	-0.6347867071209999E+00	0.1552214172196980E+240.00E+00
0.6639752607619130E+02	-0.6347867071219999E+00	0.1594141517130218E+240.00E+00
0.6639752607619130E+02	-0.6347867071230000E+00	0.1638082875818034E+240.00E+00
0.6639752607619130E+02	-0.6347867071240000E+00	0.1682988284515671E+240.00E+00
0.6639752607619130E+02	-0.6347867071250000E+00	0.1730544418193773E+240.00E+00
0.6639752607619130E+02	-0.6347867071259999E+00	0.1780372583425547E+240.00E+00
0.6639752607619130E+02	-0.6347867071269999E+00	0.1830110534267826E+240.00E+00
0.6639752607619130E+02	-0.6347867071280000E+00	0.1884192213720950E+240.00E+00
0.6639752607619130E+02	-0.6347867071290000E+00	0.1940366830259459E+240.00E+00
0.6639752607619130E+02	-0.6347867071300000E+00	0.1999170476567641E+240.00E+00
0.6639752607619130E+02	-0.6347867071309999E+00	0.2060998531770978E+240.00E+00
0.6639752607619130E+02	-0.6347867071319999E+00	0.2125112683449009E+240.00E+00
0.6639752607619130E+02	-0.6347867071330000E+00	0.2187905121564825E+240.00E+00
0.6639752607619130E+02	-0.6347867071340000E+00	0.2258244872771186E+240.00E+00
0.6639752607619130E+02	-0.6347867071350000E+00	0.2332320975378146E+240.00E+00
0.6639752607619130E+02	-0.6347867071359999E+00	0.2410570534841065E+240.00E+00
0.6639752607619130E+02	-0.6347867071369999E+00	0.2491065880114460E+240.00E+00
0.6639752607619130E+02	-0.6347867071380000E+00	0.2577210069871970E+240.00E+00
0.6639752607619130E+02	-0.6347867071390000E+00	0.2667700531612090E+240.00E+00
0.6639752607619130E+02	-0.6347867071400000E+00	0.2759999962889812E+240.00E+00
0.6639752607619130E+02	-0.6347867071409999E+00	0.2860212233708263E+240.00E+00
0.6639752607619130E+02	-0.6347867071419999E+00	0.2964524343382726E+240.00E+00
0.6639752607619130E+02	-0.6347867071430000E+00	0.3076303921884608E+240.00E+00
0.6639752607619130E+02	-0.6347867071440000E+00	0.3193718259870463E+240.00E+00
0.6639752607619130E+02	-0.6347867071450000E+00	0.3318334207454595E+240.00E+00
0.6639752607619130E+02	-0.6347867071459999E+00	0.3451108449759469E+240.00E+00
0.6639752607619130E+02	-0.6347867071469999E+00	0.3591539134708886E+240.00E+00
0.6639752607619130E+02	-0.6347867071480000E+00	0.3741651947534502E+240.00E+00
0.6639752607619130E+02	-0.6347867071490000E+00	0.3899233656004365E+240.00E+00
0.6639752607619130E+02	-0.6347867071500000E+00	0.4068716235362964E+240.00E+00
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0.6639752607619130E+02	-0.6347867071519999E+00	0.4436151269309913E+240.00E+00
0.6639752607619130E+02	-0.6347867071530000E+00	0.4641872996262146E+240.00E+00
0.6639752607619130E+02	-0.6347867071540000E+00	0.4861775406031703E+240.00E+00
0.6639752607619130E+02	-0.6347867071550000E+00	0.5096123701434384E+240.00E+00
0.6639752607619130E+02	-0.6347867071559999E+00	0.5351346910104587E+240.00E+00
0.6639752607619130E+02	-0.6347867071569999E+00	0.5624619966519761E+240.00E+00
0.6639752607619130E+02	-0.6347867071580000E+00	0.5911810151294268E+240.00E+00
0.6639752607619130E+02	-0.6347867071590000E+00	0.6208667695976938E+240.00E+00
0.6639752607619130E+02	-0.6347867071600000E+00	0.6551448022409117E+240.00E+00
0.6639752607619130E+02	-0.6347867071609999E+00	0.6924004345741584E+240.00E+00
0.6639752607619130E+02	-0.6347867071619999E+00	0.7325167628672500E+240.00E+00

0.6639752607619130E+02	-0.6347867071630000E+00	0.7766646905969253E+240.00E+00
0.6639752607619130E+02	-0.6347867071640000E+00	0.8253628736096947E+240.00E+00
0.6639752607619130E+02	-0.6347867071650000E+00	0.8760447193033331E+240.00E+00
0.6639752607619130E+02	-0.6347867071659999E+00	0.9344568345031345E+240.00E+00
0.6639752607619130E+02	-0.6347867071669999E+00	0.9980801554626862E+240.00E+00
0.6639752607619130E+02	-0.6347867071680000E+00	0.1068372936624664E+250.00E+00
0.6639752607619130E+02	-0.6347867071690000E+00	0.1146548308105281E+250.00E+00
0.6639752607619130E+02	-0.6347867071700000E+00	0.1233897187431033E+250.00E+00
0.6639752607619130E+02	-0.6347867071709999E+00	0.1331695430449130E+250.00E+00
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0.6639752607619130E+02	-0.6347867071730000E+00	0.1563768943687145E+250.00E+00
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0.6639752607619130E+02	-0.6347867071750000E+00	0.1863612388098303E+250.00E+00
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0.6639752607619130E+02	-0.6347867071950000E+00	0.2419421384098414E+270.00E+00
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0.6639752607619130E+02	-0.6347867072000000E+00	0.9307605597795105E+260.00E+00
0.6639752607619130E+02	-0.6347867072009999E+00	0.5321952742632648E+260.00E+00
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0.6639752607619130E+02	-0.6347867072030000E+00	0.2414830546932405E+260.00E+00
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